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The Unbearable Fuzziness of Spatial Data

Hunsaker, Carolyn T., Michael F. Goodchild, Mark A. Friedl, and Ted J. Case, editors. 2001. **Spatial uncertainty in ecology: implications for remote sensing and GIS applications.** Springer-Verlag, New York. xiii + 402 p. $125.00 (cloth), ISBN: 0-387-95129-6 (alk. paper); $79.95 (paper), ISBN: 0-387-98889-0 (alk. paper).

In the last two decades, advances in computing power and increases in the availability of high quality GIS data and satellite imagery have led to a steady rise in the use of spatial data in ecology. The last 10 yr, in particular, have witnessed a rapid burgeoning of the field of landscape ecology (and related spatially oriented disciplines) due to vast improvements in analytical methods and the development of easy-to-use tools for working with spatial data. However, users of spatial data should beware! The interpretations of spatial data must be tempered by a realization that the final results are only as accurate as the least accurate input into the analysis. Although most of us abide by very rigorous standards for data collection and interpretation, no absolute guarantees of positional and attribute accuracy can be made for geographic data. For a scientist, this represents a fundamental loss of control because most spatial data in one way or another originate with someone other than the scientist or final user. In addition, it is practically impossible to have a perfectly accurate and spatially complete data set. Therefore, users must either trust their data, or develop approaches to assess the impacts of spatial uncertainty in their data. This second option may seem an inconvenience, but to the editors of *Spatial uncertainty in ecology,* failure to adequately address such issues may in fact be the "Achilles' heel of attempts to turn the results of science into public policy."

Co-editors Michael Goodchild and Ted Case state that, "the outcomes of any dynamic ecological process depend directly on the initial or boundary conditions that provide its inputs." Based on this simple framework, the objective of the book is to evaluate the problems that uncertainties in these inputs create for any kind of ecological analysis. The editors define uncertainty as the state of knowledge about a spatial relationship, which can range from no knowledge (data do not exist) to complete knowledge (i.e., reality, which cannot be fully measured or represented). Uncertainty can include measurement errors, positional errors, and perhaps most importantly, fuzzy errors (those errors associated with an inability to precisely represent the state of a biological or physical system). Through a series of contributed chapters, the book attempts to address all aspects of uncertainty; its primary focus is uncertainty in base level spatial data used for ecological analyses.

Ordinarily one should approach volumes such as *Spatial uncertainty in ecology* with a healthy degree of skepticism. Books produced from working groups (in this case, the Spatial Uncertainty Working Group, supported by the National Center for Ecological Analysis and Synthesis) tend to be uneven and usually do not include results from the best research of the participants. Moreover, this particular volume risks becoming inconsequential or outdated very quickly due to rapid technical and technological advances in GIS, remote sensing, modeling, and landscape ecology, the principal topics of the book. *Spatial uncertainty in ecology* largely avoids these potential pitfalls by not attempting to be the definitive volume on the limitations of spatial data and the issues involved in incorporating spatial data into ecological studies. This is not to say the book is not comprehensive; it does, in fact, cover a wide range of topics, including remote sensing, ecosystem modeling, linear statistics, geostatistics, fuzzy sets, and the representation and communication of uncertainty in spatial data. However, the strength of the book is that it does not attempt to be a thorough literature review or provide a cookbook of solutions for those using spatial data in ecology. Rather, it offers a variety of different perspectives on spatial uncertainty in which many of the contributors illustrate their points with case studies. The focus is not on the research results, but rather on the sources of uncertainty in different types of data sets and (to a lesser extent) approaches to account for and mediate those uncertainties. As such, the book does not provide solutions for everyone, but rather provides a context for users of spatial data to assess the relevant issues and develop their own solutions. Although this can be unsatisfying at times, I found the approach to be sensible, especially since the literature on spatial uncertainty (especially in geography and remote sensing) is too vast and too dynamic to do justice in a volume such as this.

The strengths of the book lie in two places: (1) the theoretical underpinning to handling spatial uncertainty provided by the editors for the volume as a whole, and (2) the practical overviews of error in different types of spatial data. The book is ostensibly divided into two sections, the first of which (four chapters) deals with the impacts of spatial uncertainty on scientific inquiry and resource management. The second section (thirteen chapters) examines methods for assessing uncertainty. The editors have done a remarkable job tying the book together based on a simple linear model of how uncertainty is propagated in spatial data. They identify four stages at which uncertainty appears in ecological studies: data (in which uncertainty must be described), display (visualization of uncertainty), analysis/modeling (propagation of uncertainty), and decision-making (communication of confidence limits). Each author addresses in depth at least one of these stages and more generally considers all four, providing a useful linkage among chapters that are otherwise premised on fundamentally different scientific paradigms. I credit the editors with having done a very nice job tying together the different sections into a reasonably cohesive volume.

Although some readers will appreciate the specific approaches to uncertainty suggested by the contributors, I suspect that general readers will probably most appreciate the overviews provided in each chapter. By not focusing on research, but rather on the data issues affecting the research, the authors concisely convey a lot of information with surprisingly minimal (or at least well-defined) jargon. The au-

thors generally shy away from exhaustive literature reviews (which would be obsolete as of publication anyway) and instead provide readers with insights into peculiarities of particular types of spatial data. Vegetation maps, soil maps, and remotely sensed data are all addressed, as are digital elevation models, which are commonly used and misused in ecology with minimal evaluation of quality.

Readers will identify some weaknesses to the book. At the most basic level, the book tends to be very dense, especially considering that the topic is not inherently exciting to most ecologists. Most of us prefer to concern ourselves with understanding relationships between organisms and their environment rather than delving into data issues. However, the topic of the book is important, and this volume does provide a credible overview of spatial data issues. In addition, because a book such as this is not designed to be read as a whole, different sections will appeal to different types of ecologists (and geographers) depending on their interests. To that end, most ecologists who work with spatial data will find only certain sections of this book useful. There are some subjects that could have been addressed more completely in the book. Although there is one competent chapter on the use of fuzzy sets to evaluate classification accuracy, it really does not do justice to the full range of application of fuzzy set theory in ecology. Fuzzy sets can be employed to assess spatial variability and uncertainty at every step of an analysis from data input to analysis and modeling to evaluation of outputs. In addition, the book would have benefited substantially from the inclusion of a formal treatment of sensitivity analyses. Sensitivity analyses are not technically tools to assess uncertainty, but rather approaches to assess the importance of specific parameters (and their associated processes) on model predictions. However, sensitivity analyses used in conjunction with uncertainty analysis (to determine the reliability of the results) are an invaluable approach for modelers to determine which spatial inputs to an analysis yield the greatest influence in model response. Only one chapter includes an application of a form of sensitivity analysis that points to the need to consider the probability distribution of errors in data. Monte Carlo simulations are addressed in two other chapters, but again are not treated as stand-alone approaches to assessing the impacts of spatial uncertainty. Although I would not consider the lack of emphasis on sensitivity analyses to be a major omission, interested readers should probably supplement this book with additional material on this topic.

Chapters from this book would be appropriate for many graduate-level landscape ecology, ecological/ecosystem modeling, or spatial methods (remote sensing, GIS) classes. In addition, ecologists who use spatial data should periodically peruse this book to remind themselves of the many potential limitations to taking the spatial approach to ecological research. The availability of tools and data to conduct spatial analyses have greatly expanded the range and types of research that can be conducted at landscape and larger scales, and this book serves as a useful reminder of the problems that accompany spatially explicit research. The challenges are large, and there are not answers for all of the questions raised by this book. However, this volume does illustrate that methods to assess uncertainty do exist even if they are not generally applied by ecologists. Moreover, there is great potential for future research on the implications of and approaches to addressing spatial uncertainty in ecological analyses. Finally, this volume should motivate all users of spatial data to constantly re-assess their methods for handling uncertainty in any data sets that they use.

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